Biology and management of bark beetles (Coleoptera: Curculionidae) in Washington cherry orchards

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ABSTRACT

The biology and management of bark beetles (Coleoptera: Curculionidae, Scolytinae) in Washington cherry orchards was investigated from 2003-2005. Two dominant species were identified attacking cherry (*Prunus* spp.) orchards: the shothole borer, *Scolytus rugulosus* Müller, and an ambrosia beetle, *Xyleborinus saxeseni* Ratzeburg. *S. rugulosus* was the species most implicated in damage to healthy trees. Two distinct periods of *S. rugulosus* activity occur in Washington, with a possible partial third in some locations. The first activity period begins in late April and peaks in late May to early June, with the second beginning in mid-July and peaks in late July to early August. Yellow sticky traps (unbaited apple maggot traps) were effective tools to monitor *S. rugulosus* activity but ethanol-baited intercept-style traps were necessary to monitor *X. saxeseni* activity. Movement of *S. rugulosus* into orchards was closely associated with emergence from outside hosts, generally a pile of recently pruned or cut wood placed outside the orchard. *S. rugulosus* readily moved distances of 10-50 m to attack trees on orchard borders, but did not move more than two or three rows into a healthy orchard. A residue bioassay technique demonstrated that several insecticides caused mortality of *S. rugulosus* adults. A pyrethroid, esfenvalerate, was the most active 21 d after treatment. Azinphos-methyl was acutely toxic to *S. rugulosus*, but for only seven d. Endosulfan and the neonicotinyls, thiamethoxam and acetamiprid, were somewhat toxic to *S. rugulosus*.

Key Words: bark beetles, *Scolytus rugulosus*, Coleoptera, Curculionidae, Scolytinae, ambrosia beetle, *Xyleborinus saxeseni*

INTRODUCTION

Bark beetles (Coleoptera: Curculionidae, Scolytinae) have historically been reported as pests of pome and stone fruit (Kirk 1969, Linsley and MacLeod 1942, Mendel *et al.* 1987, Payne 1977, Smith 1932). They are commonly described as attacking weakened trees and causing limb or even tree death if present in high enough numbers (Lindeman 1978). Nutritionally stressed trees, or those damaged by sun scald or winter freezing may provide points of access into orchards for opportunistic beetles (Bhagwandin 1992). Health of trees is important to the natural plant defense against bark beetle attack. High plant cell turgor pressure through proper soil water availability may allow trees to mechanically flood out or chemically repel potential colonizers through increased sap flow at the site of attack (Rudinsky 1962, Berryman 1972). The use of synthetic organic insecticides has likely mitigated problems with bark beetles in tree fruit orchards, and until recently they have been considered sporadic and localized pests (Beers *et al.* 1993). However, the reported incidence of injury from bark beetles in Washington stone fruit orchards has been increasing (Brunner

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2003). Anecdotal reports attributed injury to beetles moving into orchards, especially cherry orchards, from outside hosts and attacking healthy trees. The damage most often noted is the boring of beetles at the base of buds by pioneer beetles, causing affected buds to die. Continuous and repeated attacks eventually weaken otherwise healthy trees and make them susceptible to secondary attacks from either conspecifics or possibly other wood boring beetles. Especially vulnerable are new plantings of young cherry trees. Economic difficulties in Washington's fruit industry during the late 1990s likely contributed to the bark beetle problem through an increased occurrence of neglected or abandoned orchards providing suitable host material for bark beetle reproduction (Warner 2006, Mendel *et al.* 1987).

Initial observations (2001-02) of bark beetle damage in cherry orchards indicated a need to further explore certain aspects of their biology and management. With little or no published information from Washington, species identifications and verification of life histories were required for all bark beetles infesting Washington cherry orchards. Preliminary observations indicated that the main beetle species was the shothole borer, *Scolytus sp.*, however at least one other species, possibly an ambrosia beetle, was also involved in attacking healthy cherry trees. While many other wood boring beetles were observed in and around infested hosts, their role in damage to healthy trees was either unknown or unlikely based on what was known of their natural history.

Pests invading orchards from an external host represents a significant challenge to the timing of chemical controls. Knowledge of the pest's development in host plants is needed along with its ability to migrate from these hosts into orchards. Adult traps have proven useful for monitoring bark beetles in other orchard or natural systems (Kovach and Gorsuch 1985, Markalas and Kalapanida 1997), but research is needed to identify and optimize monitoring systems for tree fruit pest management programs. Information is also needed on how much of an orchard requires protection from bark beetles, over what time periods, and which insecticides would be effective at providing required protection.

This paper provides new knowledge that will help Washington cherry growers manage bark beetle problems. The key species involved in attacking pome and stone fruit trees were identified along with a clear understanding of their seasonal life history. We also developed methods of monitoring bark beetles, and determined the distance bark beetles moved from a natal food host to attack healthy orchard trees. A bioassay technique was developed for assessing relative toxicity of candidate insecticides, and we documented successful control strategies used to manage bark beetles in heavily infested orchards.

MATERIALS AND METHODS

Bark beetle identification, monitoring, and life history. Bark beetles and other wood boring Coleoptera infesting Washington cherry orchards were identified by a combination of rearing adults from host wood infested with immature larvae in emergence cages and trapping adults near suspected host sites and along orchard borders. All insects collected in the following trials were stored in alcohol and later identified to family (Dr. Christian Krupke, Purdue University; Dale Whaley, Washington State University; Michael Doerr, Washington State University). All Scolytinae and associated parasitoids were sent to Malcom Furniss, (Entomologist *Emeritus*, University of Idaho) for identification. All Coleoptera collected from emergence cages and adult traps were identified in 2003. In 2004 only Scolytinae were submitted for identification. By 2005 it was apparent that *Scolytus spp.* were the dominant bark beetles present in Washington cherry orchards so identification was further limited to those species.

Emergence cages were used to identify a species:host relationship. Infested wood from four sites was collected during the spring and summer in 2003, placed in opaque cardboard boxes (50 x 50 x 30 cm), and held under laboratory conditions (22 ± 2 °C). One glass vial (2.5 cm diameter x 10 cm) was placed through a hole in each emergence box. Emerging beetles (and Hymenopteran parasitoids) where attracted to the light coming through the opening in the box and entered the vial. Beetles and natural enemies that entered the vial were removed daily.

Adult traps were placed near infested wood piles outside of orchard blocks (referred to below as 'outside hosts') and on the orchard border closest to the outside host at sixteen locations in north-central Washington from 2003-05 (twenty one orchard-yr equivalents). No specific protocols were followed across all sites, but rather an effort was made to ensure that trap placements sufficiently covered the threatened area of each orchard border and encircled outside hosts. Considerations had to be made depending on the size of each location. Generally, traps were placed approximately 10 m apart on orchard borders and hung directly in the trees at a height of 2 m. At least four traps were placed around a suspected outside host. If circling a host was not possible, traps were placed approximately 10 m apart across the length of the host. Most often traps were hung directly from host material, but it was sometimes necessary to hang them from a 2 m tall post that was placed adjacent to the host. Monitoring efforts in 2003 focused on identifying the best available trap and lure system. Commercially available intercept-style traps (Lindgren Funnel Trap, 8-funnnels, Phero Tech, Inc., Delta, British Columbia, Canada; Pane Intercept Trap, IPM Technologies, Inc., Portland, OR), either with or without an ethanol attractant, and un-baited yellow sticky traps (Pherocon AM, Trècè, Inc., Adair, OK) were evaluated in trials replicated across several locations for their ability to monitor adult activity at an outside host and at a nearby orchard. A 12.5 cm^2 DvDP kill strip (Vaportape II insecticidal strips, Hercon Environmental Co, Emigsville, PA) was placed in the collection container of the intercept-style traps to kill beetles and prevent their escape.

In 2003, a direct comparison was made between the Lindgren Funnel Trap and the Pane Intercept Trap at six locations. Each trap type was baited with the respective manufacturer's commercially available ethanol lure. Traps were placed on 15 April and monitored every seven d until 15 Oct. Lures were replaced at six-wk intervals, based on manufacturer recommendations. A direct comparison to evaluate the effectiveness of the ethanol attractant in the Lindgren Funnel Trap was also made at four locations in 2003. Traps were placed on 15 April and monitored every seven d for six weeks. In 2003 and 2004, a direct comparison was made between a Lindgren Funnel Trap baited with an ethanol lure and an unbaited yellow sticky trap at ten locations. In 2004, traps were placed on 1 Mar and monitored every seven d through October. The ethanol lures were replaced at six-wk intervals. Two traps of each treatment were placed in an alternating pattern at all locations. Season-long captures of the dominant Scolytinae species were averaged for the two traps at each location. Due to high variability in populations between locations, trap capture data from the paired comparisons were analyzed by a Wilcoxon Rank Test (P=0.05) (Wilcoxon 1945) using JMP statistical software (JMP v. 5.1.2 2004).

Adult trap data gathered from the locations with the highest populations (15 orchard-yr for *S. rugulosus* and five orchard-yr for *X. saxeseni*) were used to plot cumulative emergence of the dominant species for each of the generations. With no temperature-dependent developmental (degree-day) data available, the only point of reference between years was Julian days. Cumulative emergence at each date was averaged and plotted with the raw data from each orchard site. Julian days were then converted back to calendar days for ease of reference.

***Scolytus rugulosus* migration and damage distribution**. Two orchards in 2004 and two in 2005 were identified where host wood piles that were heavily infested with *S. rugulosus* were threatening nearby healthy orchards (<50 m). Yellow sticky traps were placed by the hosts located outside the orchards to track adult emergence and on the orchard borders to monitor immigration. Cumulative capture percentiles for an entire *S. rugulosus* generation at the outside host and on the orchard border were plotted together for each study site. If cumulative percentiles were identical at the host and the orchard this would suggest that adult dispersal to a suitable feeding or reproductive site occurred immediately after emergence. However, dramatic shifts in cumulative percentiles would indicate either a delay in migration from the outside host or a constant or prolonged immigration into the orchard from multiple outside hosts. Each location could only be monitored for one generation because we allowed growers to remove the natal host and protect their orchard following our observations.

At the same locations described above, damage to healthy trees in the orchard was monitored by visually inspecting trees. Every tree along the border row and then every tree in subsequent rows moving into the orchard away from the outside host were monitored for *S. rugulosus* damage until no further damage was noted. The total number of trees sampled varied at each orchard (Site 1 – 3 rows x 19 trees, Site 2 – 5 rows x 8 trees, Site 3 – 4 rows x 12 trees, Site 4 – 7 rows x 15 trees). Twenty growing shoots were randomly selected from each tree and the total number of shoots exhibiting wilting or flagging foliage (visually confirmed to be caused by *S. rugulosus* burrowing) was recorded. We calculated the total number of damaged shoots at each site, then noted what percentage of that total was found in the row closest to the outside host (row one) and each subsequent row moving away from the outside host.

***Scolytus rugulosus* insecticide screening**. Insecticides were evaluated using newly emerged *Scolytus rugulosus* adults in 2004. The insecticides outlined in the Results and Discussion section included the majority of those recommended for use on cherries in Washington (Smith et al. 2004). Although the insecticides chosen for this trial were those available on cherry, mature Delicious apple trees at WSU-TFREC were the only trees readily available for this test. The trees were treated with various insecticides at the manufacturers' recommended rates. All treatments were applied with a handgun sprayer at 300 psi to drip, simulating a full dilute spray. Treatments were applied to one-tree plots replicated three times in a randomized complete block. A one-tree buffer (unsprayed tree) was left between each replicate to reduce over-spray and drift. Treated apple branches, approximately 15 cm long x 1.25 cm diameter sections of two-yr-old wood, were collected at 1, 7, 14 and 21 d after treatment (DAT), returned to the laboratory and stored at 2 °C until new adults could be collected. Branch sections were placed into 1 L deli cups (Prime Source PS232, Dallas, TX). Untreated apple branches were used as controls for each sample date. Five arenas were prepared for each treatment. Five *S. rugulosus* adults, collected from emergence cages described above, were added to an arena and survival was recorded after 24 h (25 adults/treatment/DAT). It was assumed that the adults appearing in the vials were newly emerged, but that could not be verified. Both males and females were used in the bioassay, with no effort made to segregate by sex. We did not generate enough adults to run the entire screening at one time so adults were added to the insecticide arenas in the following order: one replicate from each treatment followed by an untreated control replicate for the one DAT samples. All replicates from this initial collection date were completed before beginning evaluations on the next series of samples (seven DAT). The process was repeated until all samples were completed. Rearing conditions were 22 °C, 16:8 L:D. Average survival and standard error of the means were reported for each treatment.

Successful *Scolytus rugulosus* management practices. During the course of this study, we documented *S. rugulosus* control efforts in four heavily infested orchards. In each situation we were contacted by growers who were already experiencing severe injury to cherry orchards. We worked with growers to monitor potential hosts, whether inside or outside of an orchard, with adult traps in an effort to identify the sources of infestation. Dissections of suspected host material (removing bark to expose live larvae) were conducted to verify *S. rugulosus* were currently utilizing the material as a natal host. We also conducted damage evaluations throughout the orchards to isolate the areas that required intervention. Once the *S. rugulosus* situation was completely described, growers implemented their own sanitation programs. We continued to monitor the orchards with adult traps throughout the clean up process and subsequently conducted post treatment damage evaluations to document the efficacy of these efforts. The methods used in these damage evaluations were consistent with those described in the trials above.

RESULTS AND DISCUSSION

Bark beetle identification, monitoring, and life history. A total of 17,116 adult Scolytinae were collected from infested fruitwood, yellow sticky traps, and ethanol-baited intercept traps. The dominant Scolytinae found throughout Washington was the shothole borer, *S. rugulosus* Müller (ver. Malcom Furniss) (Table 1). An ambrosia beetle, *Xyleborinus saxeseni* Ratzburg (ver. Malcom Furniss), was present in high numbers at only one location, a cherry orchard abandoned for several years. More than one species of Scolytinae were detected at each location where identification was not limited to *Scolytus spp*. A second *Scolytus sp*. (*S. multistriatus*) was found infesting a pile of cherry wood at only one site. Cherry has not been reported as a host (Furniss and Johnson 2002) for *S. multistriatus*, and in this case, *S. multistriatus* infested only the pile of cherry wood and was not detected moving into the neighbouring cherry orchard. Many other wood decomposing beetles were reared from infested fruitwood. In fact, the majority of Coleoptera species collected were associated with dry, older wood (dead for more than 18 mo). Buprestid (Buprestidae) and powderpost beetles (Lyctidae) were the primary beetles associated with dry wood (Table 1). *S. rugulosus* and *X. saxeseni* were the primary attackers of weakened trees or recent cuttings (<18 mo). *S. rugulosus* was the species most implicated in damage to healthy orchards, whereas *X. saxeseni* was found attacking only trees that had been previously damaged or weakened. Initial observations from laboratory emergence cages indicated that there was a high rate of parasitism (approximately 50%) of *S. rugulosus* larvae by *Cheiropachus quadrum* (Hymenoptera: Pteromalidae) (ver. Malcom Furniss) based on their relative abundance in vials from emergence cages.

No statistically significant difference was noted between commercially available intercept-style traps in their ability to capture adult *S. rugulosus* (Chi-Square 3.103, df 1, P = 0.078) but *X. saxeseni* captures were slightly higher in Lindgren Funnel Trap than Pane Intercept Trap (Chi-Square 4.021, df 1, P = 0.045) (Table 2). Both intercept-style traps should be suitable monitoring systems for *S. rugulosus* and *X. saxeseni* adults. The addition of an ethanol lure significantly enhanced captures of both *S. rugulosus* (Chi-Square 5.333, df 1, P = 0.021) and *X. saxeseni* (Chi-Square 5.333, df 1, P = 0.021). Although ethanol lures significantly increased captures of both species, this may be an area where monitoring systems could be improved. Synergistic plant volatiles (Montgomery and Wargo 1983) and/or aggregation pheromones (Lindgren *et al.* 1983, Pitman *et al.* 1975, Schroeder and Lindelow 1989, Peacock *et*

Table 1.
Wood-boring beetle collections from infested fruitwood, yellow sticky traps, and ethanol-baited intercept traps from Washington, 2003-05.

			Total annual captures in all traps[1]			
Location	**Yr**	**Host Material**	***S. rugulosus***	***X. saxeseni***	**Buprestidae**	**Lyctidae**
Wenatchee	2003	Dead cherry	13	369	5	6
Wenatchee	2003	<1-yr-old cuttings	7	16	27	20
Mallot	2003	1-yr-old pushed over apple	357	11	530	25
Okanogan	2003	<1-yr-old pushed over cherry	8654	4	25	287
Oroville	2003	<1-yr-old cuttings	695	---	---	---
Oroville	2003	Neglected apple	26	12	7	224
E. Wenatchee	2003	<2-yr-old cuttings	247	31	4	357
Wapato	2003	Neglected cherry	141	---	---	---
W. Valley	2003	Neglected cherry	637	---	---	---
Cowiche	2003	Neglected cherry	284	---	---	---
Orondo	2004	<2-yr-old cuttings	125	32	---	---
Wenatchee	2004	Dead cherry	374	196	---	---
E. Wenatchee	2004	<2-yr-old cuttings	1361	1	---	---
Okanogan	2004	<1-yr-old cuttings	218	21	---	---
Bridgeport	2004	<1-yr-old cuttings	57	6	---	---
Bridgeport	2004	<1-yr-old cuttings	6	1	---	---
Tonasket	2004	<1-yr-old cuttings	170	2	---	---
Okanogan	2005	<2-yr-old cuttings	1247	---	---	---
Orondo	2005	<2-yr-old cuttings	743	---	---	---
E. Wenatchee	2005	<2-yr-old cuttings	292	---	---	---
Moses Lake	2005	Neglected cherry	761	---	---	---

[1] ---, Insects not collected for identification.

al. 1972) have been used to improve monitoring systems for some bark beetle species, unfortunately not all species aggregate in response to pheromone production (Macías-Sámano *et al.* 1998). It is unclear if *S. rugulosus* or *X. saxeseni* produce aggregation pheromones.

Adult *S. rugulosus* were more highly attracted to the yellow sticky traps (Chi-Square 9.143, df 1, P = 0.003), than the dark coloured ethanol-baited intercept-style traps. Yellow sticky traps proved to be easy to deploy and read, and were relatively economical compared to the intercept-style traps. The ethanol-baited intercept-style traps were necessary to monitor *X. saxeseni* activity (Chi-Square 12.799, df 1, P = 0.0003), but our experience has been that this species is a minor contributor to damage in commercial cherry orchards.

Two distinct periods of *S. rugulosus* activity occurred in Washington (Fig. 1). *S. rugulosus* activity was first noted in late April or early May and continued through June. The second adult flight was detected in mid- to late July and continued through August and into late-September. Adult *S. rugulosus* were trapped through the entire growing season from initial adult emergence through the end of October. A slight increase in trap captures occurring at the end of each season suggested the possibility

Table 2.
Mean (± SEM) *S. rugulosus* and *X. saxeseni* captures using commercially available trap and lure systems, 2003.

Mean adults/trap (SEM)[1]				
S. rugulosus		***X. saxeseni***		N[2]
Pane Intercept With Ethanol Lure 68.3 (34.7)	Lindgren Funnel With Ethanol Lure 121.3 (59.3)	Pane Intercept With Ethanol Lure 21.3 (16.4)	Lindgren Funnel With Ethanol Lure 31.0 (22.2)*	6
Lindgren Funnel With Ethanol 109.1 (66.2)*	Lindgren Funnel Without Lure 59.5 (50.3)	Lindgren Funnel With Ethanol 33.9 (29.4)*	Lindgren Funnel Without Lure 7.0 (6.3)	4
Lindgren Funnel With Ethanol 34.9 (27.0)	Yellow Sticky Card 226.6 (188.6)*	Lindgren Funnel With Ethanol 22.7 (14.4)*	Yellow Sticky Card 0.6 (0.4)	10

[1] Means followed by '*' are significantly different (Wilcoxon Rank Test, P = 0.05)
[2] N, number of sites in study

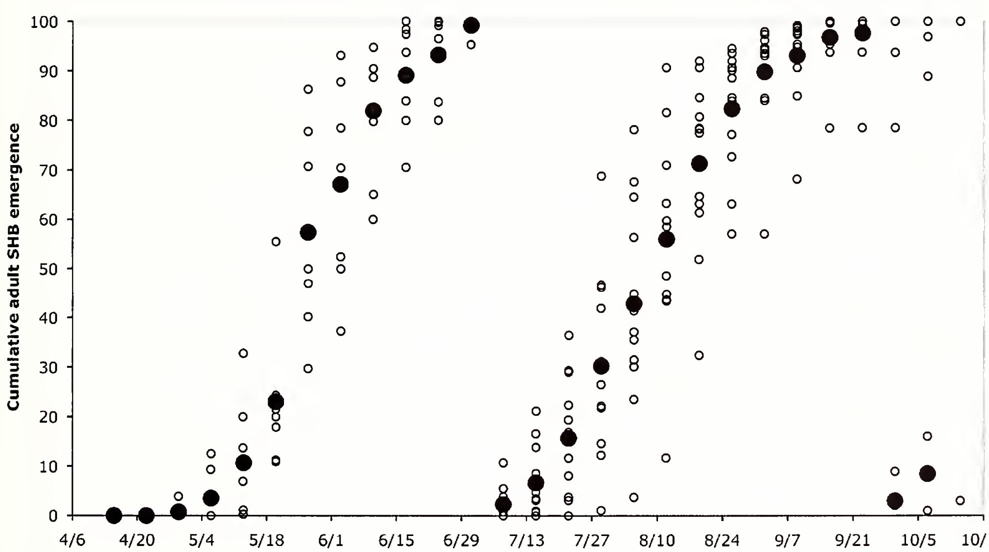

Figure 1. Cumulative emergence of *S. rugulosus* adults (n=5,675) in Washington, 2003-05. Open circles represent cumulative emergence from each location, black dots represent the average emergence on each date. SHB = shothole borer.

of a partial third generation.

Adult *X. saxeseni* activity occurred throughout the entire growing season, with peaks suggesting the presence of three to four generations (Fig. 2). Adult *X. saxeseni* activity was initially noted in late March or early April. A second peak of activity occurred in early June, with a third noted in July and early August. A slight increase *X. saxeseni* activity was observed in September and early October, although at reduced numbers. It is unclear if this activity represented part of a fourth generation or prolongation of the third.

Traps were useful in identifying peak activity periods of *S. rugulosus* but it was not clear if they would be useful in setting thresholds for treatments. We had trouble locating *S. rugulosus* sources with various population sizes near neighboring cherry orchards that were allowed to remain untreated. Since insecticides were applied

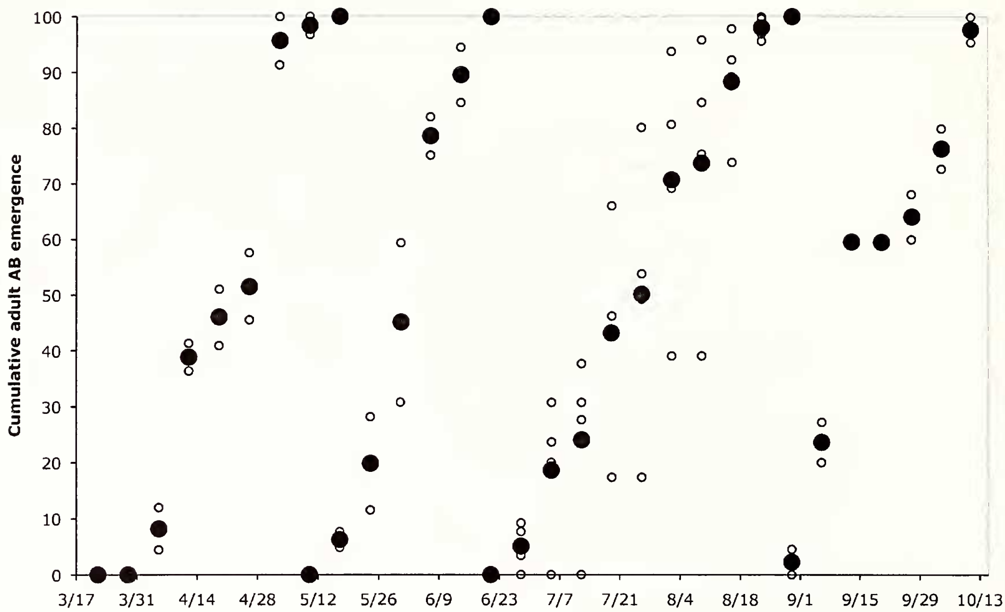

Figure 2. Cumulative emergence of *X. saxeseni* adults (n=805) in Washington, 2003-04. Open circles represent cumulative emergence from each location, black dots represent the average emergence on each date. AB = ambrosia beetle.

frequently in cherry orchards for control of other pests, it was difficult to establish a consistent relationship between trap captures and subsequent damage. However, our observations indicated that if an *S. rugulosus* host was located near a cherry orchard and any significant emergence was detected with yellow traps, some control intervention would be justified to prevent damage.

***Scolytus rugulosus* migration and damage distribution.** Movement of *S. rugulosus* into healthy orchards was closely associated with emergence from a nearby infested host, generally a pile of recently pruned or cut wood placed outside the orchard (Fig. 3). Cumulative captures of adults at the outside host and at the border of the nearby orchard were closely associated at each study site. There was no consistent pattern of either a lag in percentiles, or prolonged captures at the orchard border. In other words, observations at the more heavily infested outside hosts were representative of what was occurring at the orchard borders. Further, *S. rugulosus* activity was easier to monitor at the host than in healthy trees (1819 and 258 total *S. rugulosus* adults, respectively) as a very large number of adults emerged from a relatively small area and dispersed immediately. These data indicated that growers should be able to focus their efforts at locating and monitoring suspected outside hosts, understanding that as adult activity increased at the hosts, immigration to healthy orchards was occurring simultaneously. It appeared that recently emerged *S. rugulosus* adults were highly dispersive and readily moved distances of at least 50 m from infested outside hosts to healthy trees in orchard borders. After dispersal, adult activity in and around suitable natal hosts continued where behaviour appeared to be associated with the construction and care of maternal galleries. This aspect of *S. rugulosus* behaviour needs to be explored further.

S. rugulosus adult feeding damage to healthy trees was most commonly associated with movement from infested hosts. Generally, *S. rugulosus* damage was in close proximity to that host. It appeared that *S. rugulosus* moved readily to and along an orchard border, but did not move more than two or three rows into a healthy orchard. On average, 74% of the total *S. rugulosus* damage that was detected in healthy or-

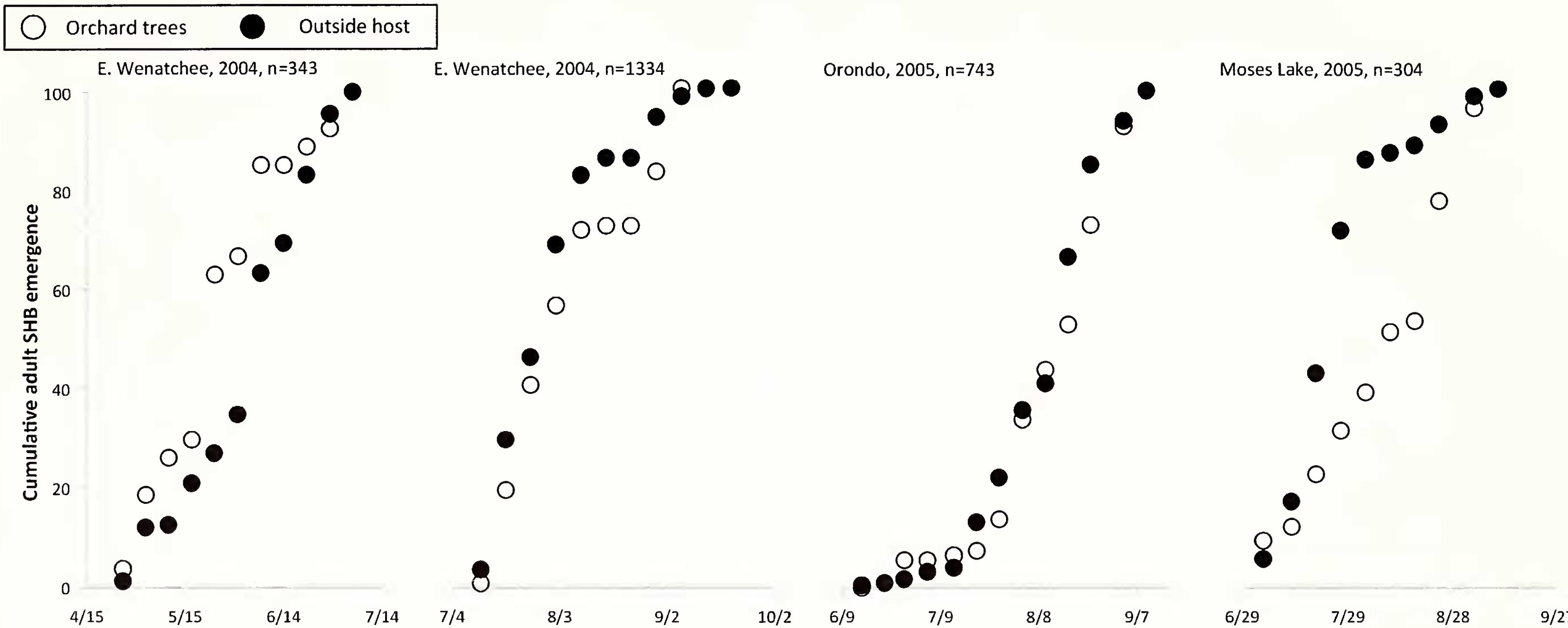

Figure 3. Cumulative captures of *S. rugulosus* on yellow sticky traps from infested host wood piles ('outside host') and the borders of nearby healthy cherry orchards, 2004-05. SHB = shothole borer.

chards occurred on the border row closest to the natal host (Fig. 4). Twenty percent of the total damage was found on the second row. Damage in subsequent rows was minor and scattered. These data indicated that monitoring and control efforts should be focused on determining the natal host responsible for *S. rugulosus* infestation, usually piles of recently cut wood near orchards, and then protecting the area of the orchard immediately adjacent to that host. If control is neglected, trees will become weakened and *S. rugulosus* will successfully colonize and reproduce in the weakened trees. Once this occurs immigration is not the sole source of beetles and damage will spread further into the orchard thereby complicating management efforts.

***Scolytus rugulosus* insecticide screening**. Once introduced into the treatment arenas, adult *S. rugulosus* began feeding or attempting to colonize the limb sections immediately. Although the purpose of this behaviour was not known (feeding or oviposition), the beetles were very active on the treated wood. The average survival of *S. rugulosus* adults on untreated wood was 96% after 24 h. This level of survival indicated any significant mortality could be attributed to pesticide exposure and not a problem with the bioassay method.

Many insecticides caused mortality of *S. rugulosus* in the bioassays (Table 3). A pyrethroid, esfenvalerate, was the most active through 21 d. Azinphos-methyl was acutely toxic to *S. rugulosus*, but for only seven d. Endosulfan and the neonicotinyls, thiamethoxam and acetamiprid, were somewhat toxic to *S. rugulosus*. Malathion, indoxacarb, and spinosad all caused mortality, but not at levels expected to provide adequate control under field conditions. Additional insecticide efficacy trials are necessary to understand the full potential of each insecticide to control *S. rugulosus* under field conditions. The repeated use of these insecticides against other pests, primarily the cherry fruit fly, *Rhagoletis indifferens* Curran (Diptera: Tephritidae), during the early part of the growing season is likely sufficient to suppress damage in most commercial orchards, especially during the first *S. rugulosus* generation. Cherry orchards may become more susceptible to injury in the post-harvest period when insecticide programs for cherry fruit fly and leafroller (Lepidoptera: Tortricidae) have ceased. Second-generation *S. rugulosus* adults would then be able to move into unprotected orchards.

Successful *Scolytus rugulosus* management practices. Sanitation has generally been touted as the key to control, with wood or brush piles identified as contributors of beetles that migrate and attack other trees (Bhagwandin 1992, Beers *et al.* 1993, Payne 1977). In the winter of 2003-04, we monitored an effort to clean up a large infestation of *S. rugulosus* emerging from an outside host that had resulted in significant damage to young, healthy cherry trees. In 2003, approximately 55% of shoots in the trees along the orchard border at this location were damaged despite several insecticide applications, including repeated applications of endosulfan. The outside host was a firewood and brush pile that was replenished each year. While the damage was high, it was fairly well isolated from the orchard border rows adjacent to the host. During the winter of 2003-04, the orchard was pruned heavily, removing all weakened or damaged branches and the grower made a concerted effort to clean up all host material (firewood, brush piles, and current-yr cuttings) and maintain a clean area near the orchard. During the 2004 growing season, the orchard was monitored with yellow sticky traps and ethanol-baited intercept-style traps. Insecticide applications were planned to coincide with increased trap captures. However, a total of only four *S. rugulosus* and nine *X. saxeseni* adults were trapped in five yellow traps and four intercept-style traps and therefore no insecticide applications specifically for control of bark beetles were needed. No *S. rugulosus* damage was noted at any time during the 2004 season demonstrating that the sanitation efforts were the only control measure needed.

In 2005, we monitored efforts at three

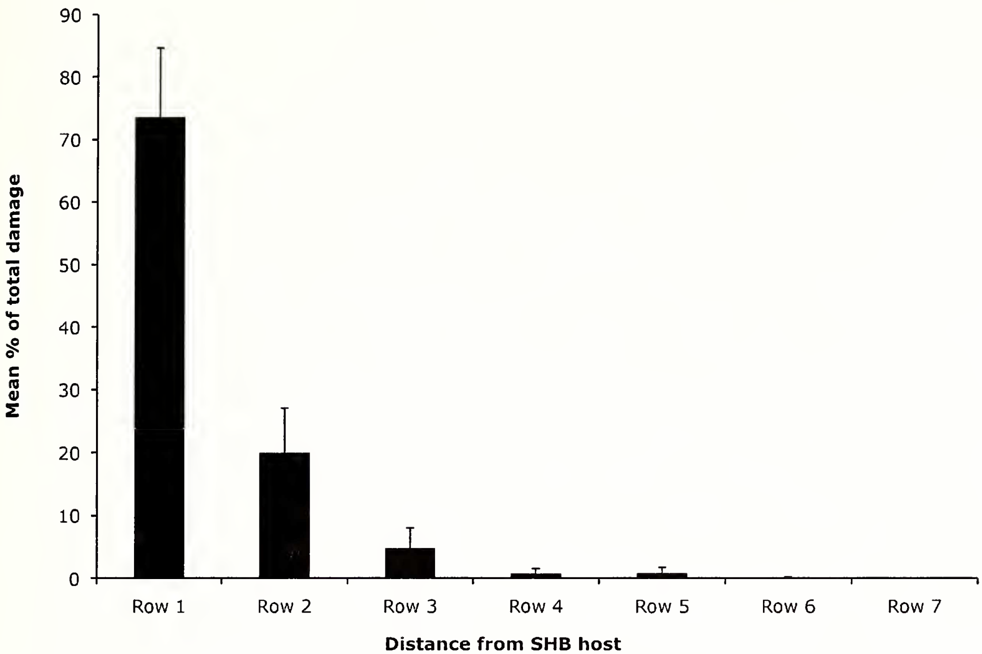

Figure 4. Mean (±SEM) percentage of total damage noted in each orchard (n=4) at the row adjacent to the source of *S. rugulosus* (Row 1), and subsequent rows moving into the orchard, 2004-05. SHB = shothole borer.

Table 3.
Mean (±SEM) *S. rugulosus* survival on field-aged residues of insecticides, 2004.

Insecticide	Active Ingredient	Rate gm ai/ha	Mean no. live *S. rugulosus* (SEM) – 24 h			
			1 DAT[1]	7 DAT	14 DAT	21 DAT
Asana XL 0.66EC	Esfenvalerate	46.8	0.0 (0.0)	0.4 (0.2)	0.0 (0.0)	0.8 (0.4)
Guthion 50WP	Azinphosmethyl	1,135.0	0.0 (0.0)	0.4 (0.2)	2.4 (0.7)	4.0 (0.3)
Actara 25WDG	Thiamethoxam	80.0	0.6 (0.6)	1.0 (0.3)	2.0 (0.9)	1.8 (0.7)
Assail 70WP	Acetamiprid	168.7	0.6 (0.6)	1.4 (0.6)	1.8 (0.6)	0.8 (0.4)
Thiodan 3E	Endosulfan	2,552.5	0.7 (0.3)	1.3 (0.3)	1.7 (0.3)	1.3 (0.9)
Avaunt 30WDG	Indoxacarb	127.8	2.0 (0.5)	2.0 (0.7)	0.8 (0.4)	2.6 (1.1)
Malathion 50%EC	Malathion	300.0	2.2 (0.8)	2.8 (0.6)	4.2 (0.4)	3.8 (0.7)
Success 2SC	Spinosad	106.4	3.8 (0.2)	3.6 (0.7)	4.2 (0.4)	3.6 (0.7)
Untreated			5.0 (0.0)	4.8 (0.2)	5.0 (0.0)	4.4 (0.2)

[1] DAT, Days After Treatment

locations near Okanogan, WA to clean up easily identifiable infested hosts of *S. rugulosus* located just outside of cherry blocks exhibiting signs of recent feeding damage. In addition to the external hosts, weakened limbs and one-yr-old cuttings left in the orchards were also serving as host material for *S. rugulosus* reproduction within the cherry blocks. These sites were brought to our attention after first generation beetles had caused serious damage to trees in the orchard borders. Insecticidal control options were limited as one of the blocks was managed organically, and the conventional blocks were experiencing damage levels of 50% shoot infestation despite a history of border sprays. Although yellow traps used to determine what host material was serving as the source of the *S. rugulosus* infestations were placed near the end of first generation activity, captures in the first seven d averaged 116 *S. rugulosus* per trap across all three locations. Subsequently, the growers removed all possible host material within the orchard, including the previous winter's cuttings and weakened branches or limbs. This wood was added to the host material located outside the orchard and targeted with an intensive insecticide treatment program. Endosulfan was applied by a handgun sprayer on a 10-14 d retreatment interval for the rest of the season with care taken to thoroughly soak the entire wood pile. Following this action, no second-generation beetle activity was noted at any of the three sites, and no new damage was detected inside the orchard.

Healthy cherry trees can repel initial colonization efforts by *S. rugulosus* adults by flooding attacked sites with resin, but with repeated attacks even healthy trees will eventually become weakened, allowing successful colonization by secondary attacks from conspecifics (Bauernfeind 1996, Payne 1977). Our experience with *S. rugulosus* management indicates orchard sanitation is the most important factor contributing to a reduction in *S. rugulosus* populations and damage to healthy cherry trees. If recent feeding damage is noted on otherwise healthy trees, adult traps can be placed on the orchard borders or in suspected host areas to verify the source of infestation. Sanitation programs must include removing potential host material (weakened limbs or recent cuttings) from within the orchard and eliminating any host material outside the orchard. Beetle host material outside the orchard can be eliminated by burning or by thoroughly soaking the wood with an effective insecticide delivered by a handgun sprayer. The increased volume of water delivered by handgun applications appears to be an important factor in insecticide efficacy. We do not believe growers can rely on traditional insecticide applications via an air-blast sprayer to control infestations that originate from within the orchard, or protect orchard borders from massive immigration originating from a nearby heavily infested host.

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